BOOK REVIEW

Structural Synthesis of High-Accuracy Automatic Control Systems. By M. V. MEEROV. Pergamon Press, Oxford, 1965. (Translated from the Russian by J. P. Ruban.)

This book is primarily concerned with the problem of designing linear control systems that are stable when the gain is indefinitely increased to improve static accuracy. Emphasis is on the general properties that various system configurations may have in view of the above design goal. There is little concern for detailed parameter optimization since this can be readily carried out by computer once the allowable parameter ranges have been established.

In Chapter I, the mathematical problem to be treated is formulated as: Given fixed elements, how does one organize the control system and select the parameters so as to meet dynamic performance specifications? The adjective "structural" is used with the implication that specific properties could be achieved without being concerned with numerical parameter values that actually achieve the desired performance. Thus, for example, the "structural" requirement that a system be critically damped implies that an arrangement of the control system block diagram and literal forms for compensation be possible, such that parameters could be adjusted to produce critically damped behavior. The actual values of the parameters that are needed to achieve the desired performance are not of interest, but the fact that values of these parameters can be found to satisfy performance specifications is the primary consideration. The most important use of the concept is in "structural stability with indefinite increase in gain," and a good portion of the book is devoted to examining various system configurations along with assumed types of fixed-element transfer functions to see whether or not they are structurally stable with infinite gain.

Chapter I presents also the basic quantitative tool, namely, the D-decomposition curve for analysis and design. This method is closely related to the use of the inverse polar locus in American literature. Thus, for example, consider a unity feedback loop with the open-loop frequency response $KG(j\omega)$. The closed-loop response can be written as

$$W(j\omega) = \frac{K}{K + G^{-1}(j\omega)} .$$

The equation $\bar{K} = -G^{-1}(j\omega)$ represents the stability boundary in terms of the complex gain, $\bar{K}$. Thus in the plane Im $\bar{K}$ versus Re $\bar{K}$, a plot of $-G^{-1}(j\omega)$ (with frequency ω as parameter) divides the plane into two regions. By noting in which region the real axis lies for a given value of K, stability is immediately determined. Given a value of K that insures stability, most of the important properties of $W(j\omega)$ and its associated transient response (for a step input) can be readily determined.

Chapter II treats single-loop systems with one control input and one compensator which is either a feedback device or a feedforward device. (The use of cascade compensation is not considered at all in this book.) The key approach to analysis of behavior with high gain is first presented. By writing the characteristic equation and then letting the gain become infinite, a degenerate stability equation results. If the roots of this degenerate equation lie in the left half-plane then the system exhibits structural stability with infinitely high gain. Obviously, it can happen that, for finite values of gain, roots can lie in the right half-plane. Thus the systems that result are often conditionally stable.

Chapter III is concerned with the use of many compensators in a single-loop system. Theorems are derived relative to the stability question that limit the type, order, and number of compensators, given the type, order, and number of fixed elements. A variety of configurations are examined and the effect of pure time delay is also considered. Meerov shows that there are systems with pure delay which, if properly compensated, are structurally stable with infinite gain. He also demonstrates why pure derivative compensation often fails and shows that the use of higher derivatives may degrade performance even in the absence of noise.

Chapter IV is devoted to answering the question: Is a given structure or configuration capable of meeting required performance specifications? Thus, with fixed and adjustable parameters, when can we always be able to vary the adjustable parameters so as to meet the performance requirements? The approach is first to insure structural stability with infinite gain (to meet any accuracy specifications) and then to show that a structure is possible with adjustable parameters that admits any speed of response and overshoot specifications.

Chapter V is concerned with the effects of nonlinearities other than saturation and uses the describing function or harmonic balance method. Meerov shows that systems designed according to his philosophy closely approximate the behavior of minimum-time optimal control systems. He points out that some of the minimum-time systems discussed in the literature are unstable, and he then proceeds to show how they can be stabilized without appreciably disturbing the optimum behavior.

Chapter VI is concerned with the problem of sensitivity, particularly with regard to parasitic time constants that have been neglected in the models of the fixed elements. He is concerned with determining the conditions under which conclusions about a system being structurally stable with infinite gain may have to be modified. Chapter VII deals with multidimensional systems and the problem of designing noninteracting systems.

The book taken as a whole presents an interesting and novel approach to the design of linear control systems. Although the author considers some nonlinearities heuristically, ignoring the effect of saturation raises a serious question about the practical application of the method. It is well-known that conditionally stable systems with saturating elements can exhibit severe oscillations. Occasionally, by using nonlinear compensators, these oscillations can be suppressed, but with very complex systems it is very difficult to see how to design such compensators. If attention is limited to purely linear systems, many of Meerov's results could be more simply obtained from the state-space point of view by determining appropriate transformations of the system equations to normal coordinates and then altering the eigenvalues to any desired values. As long as one can measure the states perfectly, any linear system without delay can be made to exhibit fast, stable response with high accuracy. Since Meerov does not consider the effects of noise on system performance but only treats deterministic problems, it is questionable whether his results are as widely applicable as might be assumed from a first glance at his work.

A variety of numerical examples are given, all of which are concerned with control systems involving electrical machinery, such as speed control systems, servomechanisms, and voltage and frequency regulators. The Bibliography consists almost entirely of references to the Russian literature and the Index is too brief to be particularly useful. The book suffers in translation because English or American terminology is not used. The reader has to develop his own glossary as he goes along and this can become rather tedious.

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